Oscillatory Compressible Thermal Convection in vertical and inclined differentially heated cavities

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Motivations and Objectives

- **To study** the phenomena occurring in convective flows of thermogravitational nature inside closed geometries taking into account compressibility and variable viscosity effects.
- **Applications:** cooling of high-power devices, solar energy, nuclear power plants...
- **To compare** the numerical results provided by a variable-properties model and other simulations based on the classical approximations.

The Methodology

- **We used two different numerical methods, one based on the canonical Boussinesq model (constant properties) and the other accounting for variable-properties (including density) effects.**
- **The compressible solver relies on the equation of state for a perfect gas.**
- **Both solvers are based on the coupled velocity-pressure approach (PISO algorithm implemented in OpenFoam).**
- **The related governing equations are shown below:**

Compressible

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial}{\partial t}[\rho \mathbf{u}] + \nabla \cdot [\rho \mathbf{u}\mathbf{u}] - \nabla \cdot [\mu \nabla \mathbf{u}] = -\nabla p + \rho \mathbf{g}$$

$$\frac{\partial}{\partial t}[\rho h] + \nabla \cdot [\rho \mathbf{u} h] - \nabla \cdot [\alpha \nabla h] = \frac{Dp}{Dt}$$

$$\rho = \frac{p}{R_{gas} T}$$

Incompressible

$$\nabla \cdot \mathbf{u} = 0$$

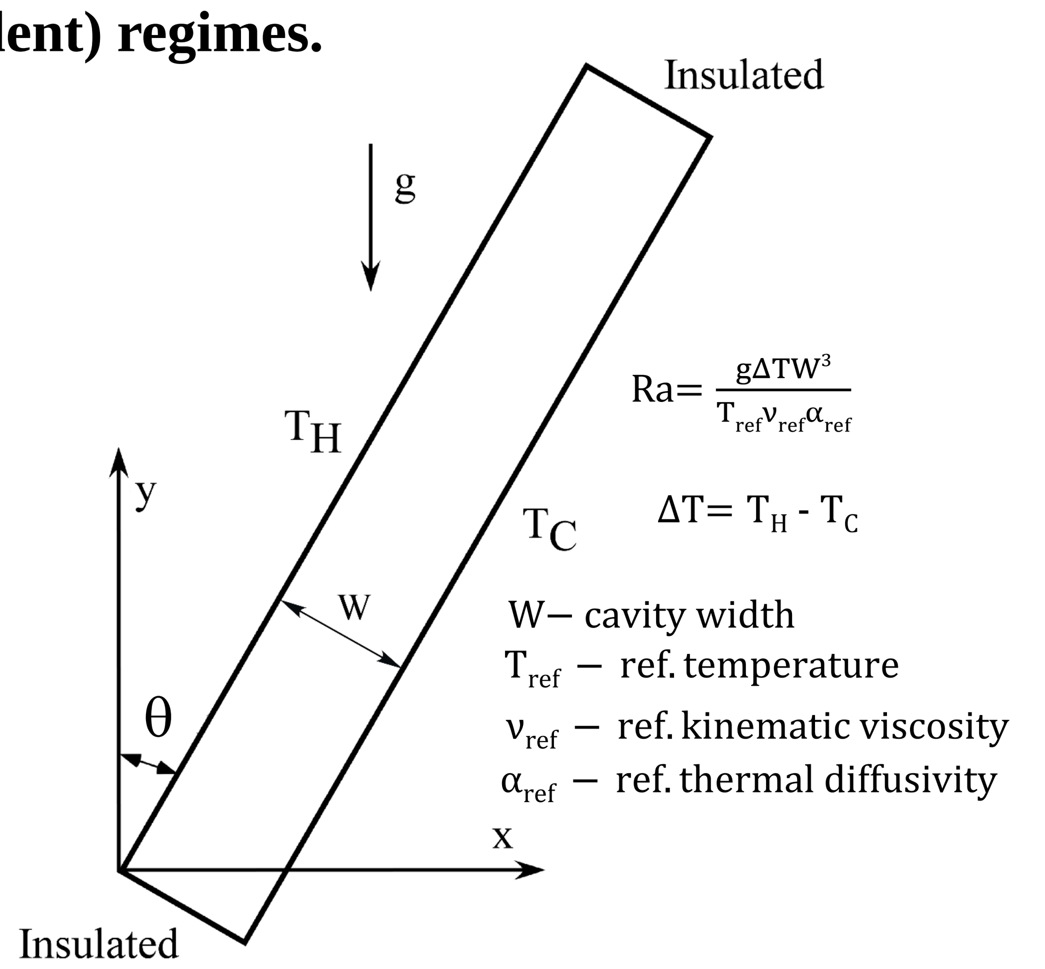
$$\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot [\mathbf{u}\mathbf{u}] - \nu_{ref} \nabla^2 \mathbf{u} = -\frac{1}{\rho}\nabla p + \mathbf{g}[1 - \beta(T - T_0)]$$

$$\frac{\partial T}{\partial t} + \nabla \cdot [\mathbf{u}T] = \alpha_{ref} \nabla^2 T$$

β – thermal expansion coefficient

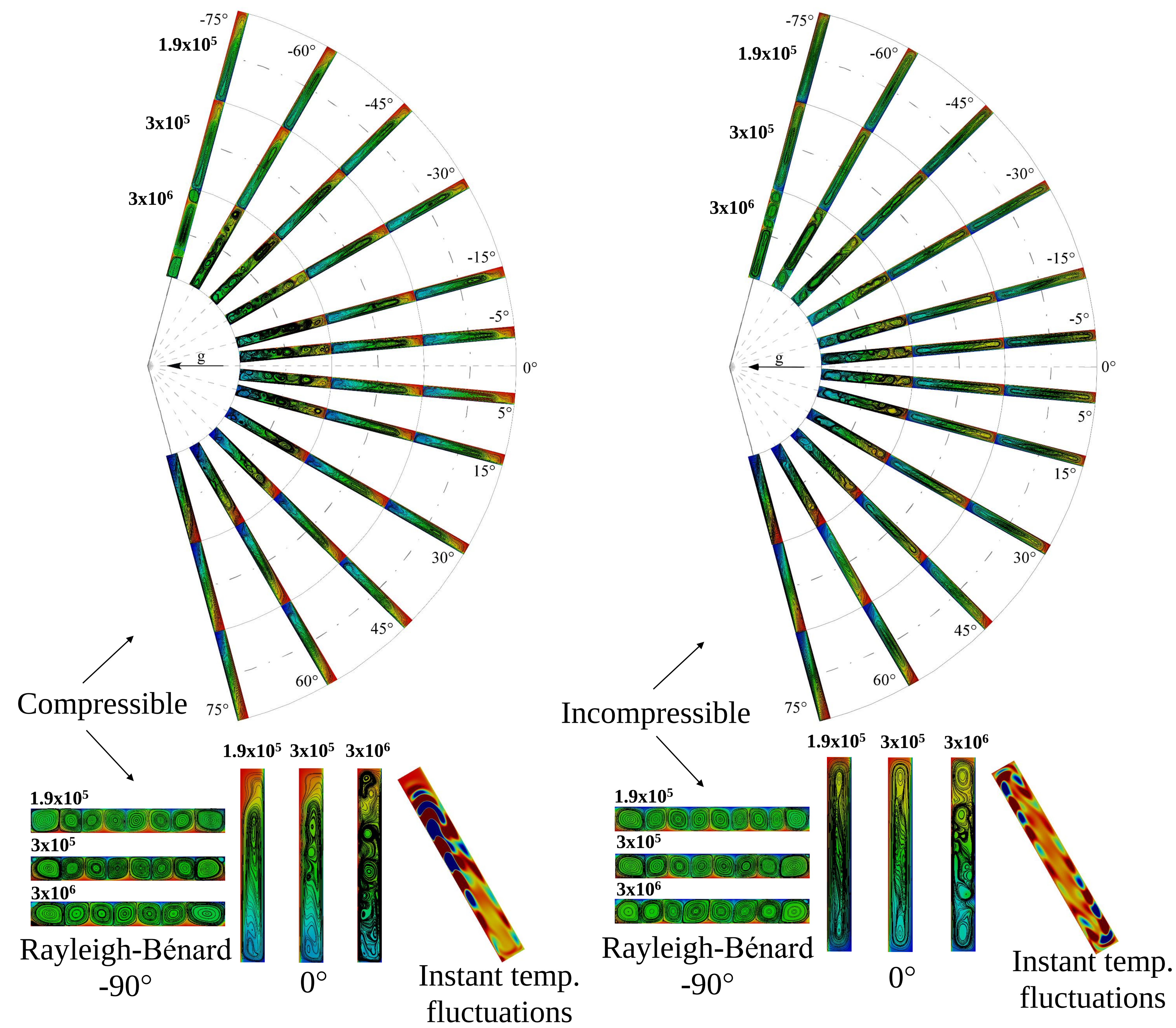
The Problem

- **Thermal convection of air in a differentially heated inclined tall cavity for different values of the inclination angle and different (laminar and turbulent) regimes.**

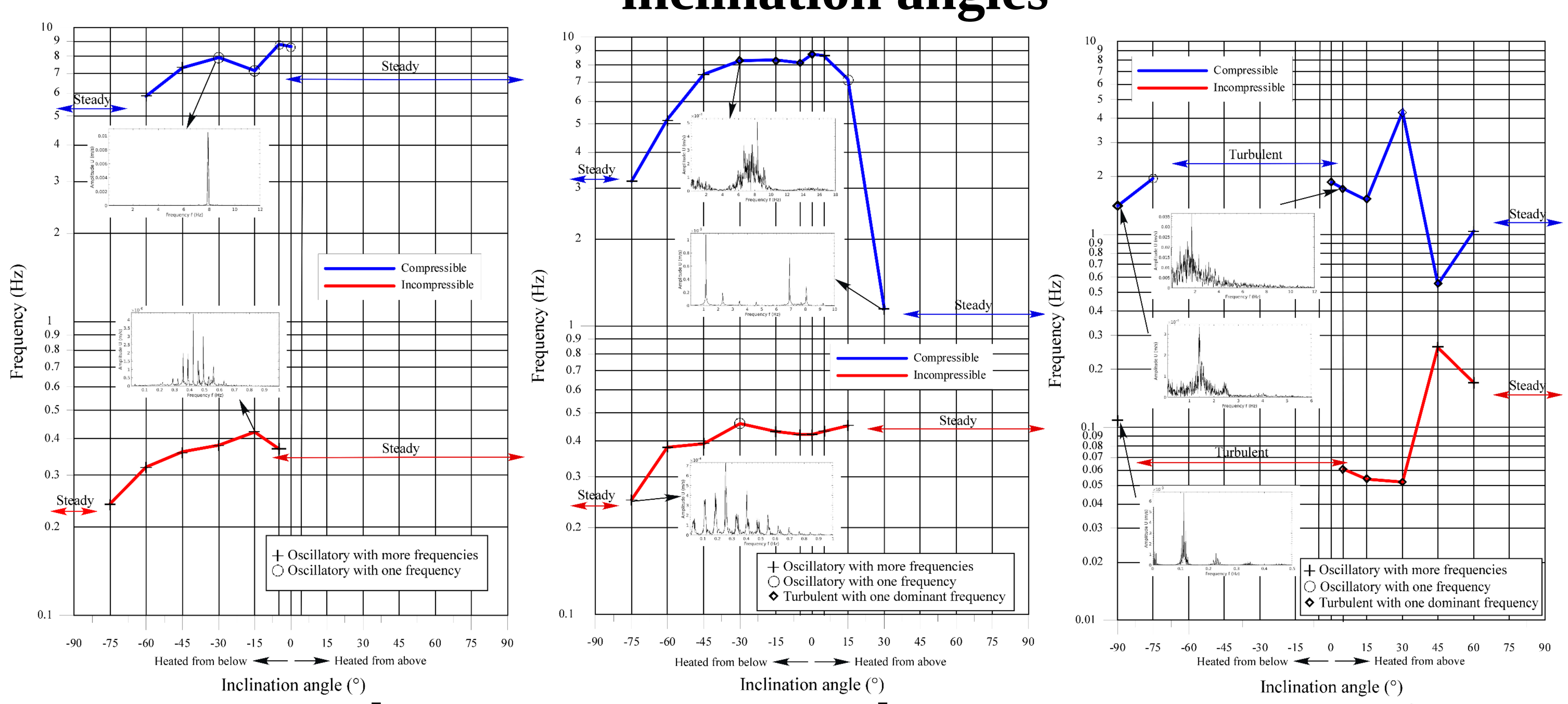


- **When the cavity is vertical, the flow is in the so-called boundary-layer regime (thermal boundary layers located in proximity to the vertical walls and vertical stratification in the center).**
- **When the inclination is changed, the flow is affected by different thermal and hydrodynamic instabilities.**
- **We performed a set of simulation covering the following ranges ($1.9\times10^5 \leq Ra \leq 3\times10^6$, $-90° \leq \theta \leq 90°$).**

Comparison of compressible and incompressible flow patterns at different Rayleigh number and inclination angles



Frequency analysis for different Rayleigh number and inclination angles



Ra=1.9×10^5 Ra=3×10^5 Ra=3×10^6

Conclusions and Future Work

- **Numerical results revealed a variety of different possible flow patterns (boundary layer instability, standing or travelling vortices.)**
- **The flow is much more unstable when compressibility and variable viscosity effects are taken into account (earlier transition to oscillatory flow and more complex frequency spectra).**
- **We plan to include chemistry models and/or models for solid particle tracking.**